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Evaluation of Shortnose Sturgeon Spawning in the Pinopolis Dam Tailrace, South Carolina

MICHELLE S. DUNCAN

Department of Aquaculture, Fisheries, and Wildlife, Clemson University, Clemson, South Carolina 29634-0362, USA

J. JEFFERY ISELY*

U.S. Geological Survey, South Carolina Cooperative Fish and Wildlife Research Unit, Clemson University, Clemson, South Carolina 29634-0372, USA

DOUGLAS W. COOKE

South Carolina Department of Natural Resources, Dennis Wildlife Center, Post Office Box 190, Bonneau, South Carolina 29431, USA

Abstract.—Fifty egg mats and up to five D-shaped plankton nets were deployed in the tailrace of Pinopolis Dam at river kilometer 77 on the Cooper River, South Carolina, to evaluate the spawning activity of shortnose sturgeon *Acipenser brevirostrum*. Spawning times were estimated by back-calculation based on developmental phase. Eggs were collected on 17 of 21 d sampled continuously from March 4 through March 25, 2002, when water temperatures were 10–16°C. A total of 31 shortnose sturgeon eggs were collected from egg mats. An additional 338 shortnose sturgeon eggs and 1 newly hatched yolk sac larva were collected from plankton nets. A minimum of 20 spawning events occurred in the tailrace during the 2002 spawning season. No relationship between mean daily discharge and spawning date was observed. Shortnose sturgeon spawned more often during the night than at any other time of day independent of generation.

The shortnose sturgeon *Acipenser brevirostrum* commonly inhabits mesohaline areas of large rivers along the Atlantic coast from the St. Johns River, Florida, to the St. John River, New Brunswick, Canada (Vladykov and Greeley 1963; Dadswell 1984). After many years of overfishing and loss of access to spawning habitats, the shortnose sturgeon is now protected under the Endangered Species Act (Miller 1972; Dadswell 1984).

Shortnose sturgeons migrate upstream to spawn during spring in northern rivers and in late winter in southern rivers (Dadswell 1979; Kynard 1997). Southern stocks generally migrate upstream at least 200 km from the saltwater–freshwater interface (Kynard 1997). Female shortnose sturgeons reach maturity at fork lengths of 50–60 cm and spawn for the first time when 55–75 cm (Dadswell 1984); males mature at 45–50 cm. Although males spawn every 1–2 years, the minimum duration between spawning events for females is generally 3 years (Dadswell 1979; Cooke et al. 2002). Spawning occurs when water temperatures reach 9–15°C (Dadswell 1979; Taubert 1980; Kynard 1997). Although fecundity varies among populations, females usually produce 40,000 to 200,000 eggs (Dadswell 1979). Once fertilized, the highly adhesive and demersal eggs adhere to the river substrate (Dadswell 1984; Kynard 1997). Substrates commonly used by spawning shortnose sturgeon include gravel, rubble, large rock, sand, logs, and cobble (Dadswell 1979; Taubert 1980; Kieffer and Kynard 1996; Kynard 1997). Shortnose sturgeon eggs generally hatch from 6 and 12 d after spawning at temperatures of 11–18°C (Buckley and Kynard 1981; Smith et al. 1985). Once hatched, the larvae emerge and migrate downstream (Richmond and Kynard 1995).

Moderate river flow is needed to promote spawning (Buckley and Kynard 1985). However, low or high discharge can inhibit spawning success by either allowing eggs to clump together or by not allowing eggs to adhere to the substrate (Dadswell 1979; Buckley and Kynard 1985; Kynard 1997). Shortly after hatching, sufficient flow is also required to transport shortnose sturgeon larvae downstream to nursery areas (Buckley and Kynard 1985; Kynard and Horgan 2002).

Little is known about the shortnose sturgeon population in Cooper River, South Carolina. Cooke and Leach (1999) found that shortnose sturgeon congregate and spawn below Pinopolis Dam, the first obstruction to upstream migration. Short-

* Corresponding author: jisely@clemson.edu

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nose sturgeon in Cooper River initiated upstream spawning migrations in January and remained in Pinopolis Dam tailrace for an extended period during the spawning period (Palmer 2001). Although some spawning takes place near the dam, the effects of turbine discharge on spawning activity has not been evaluated. To date, no larvae or juveniles have been observed in Cooper River. In unobstructed rivers, shortnose sturgeon often migrate over 200 km to preferred spawning grounds (Dadswell 1984; Kynard 1997).

The objectives of this study were to further document shortnose sturgeon spawning activity in the Pinopolis Dam tailrace and to quantify the relationship between spawning activity and temperature, turbine discharge, and time of day.

Study Area

The study area consists of the tailrace of Pinopolis Lock and Dam. Pinopolis Lock and Dam, at rkm 77, is the first obstruction on Cooper River, which flows southeast to Charleston Harbor in coastal South Carolina. The dam was completed in 1941 to provide flood control, navigation, and hydroelectric power. The hydroelectric station, which consists of four turbines, discharges between 0 and 329 m^3/s. Water depth in the tailrace is regulated by generation discharge and tidal stage. The bottom is uniform in depth and averages 4 m under non-power-generation periods, but can increase to an average of 5 m in depth during periods of generation. Water velocity varies from 0 $m \cdot sec^{-1}$ during non power generation to more than 2 m/s during power generation. The bottom substrate in the tailrace is primarily hard, packed clay with patchy deposits of Asian clam *Corbicula manilensis* shell. The riverbanks in the tailrace region have been stabilized with rock riprap. The substrate along the banks ranges from cobble to boulder-size rock.

Methods

Fifty egg mats were deployed in the tailrace of Pinopolis Dam (Figure 1). Egg mats were placed in a grid pattern, 15 to 20 m apart, within an area approximately 100 m × 150 m below Pinopolis Dam. Previous studies documented shortnose sturgeon spawning in this area (Cooke and Leach 1999). The egg mat, modified from Marchant and Shutters (1996), consisted of a white commercial floor-buffing pad (50-cm in diameter) attached to a length of 1-cm-diameter reinforcement bar bent into a circle of the same diameter. Two 100-cm lengths of straight reinforcement bar were attached

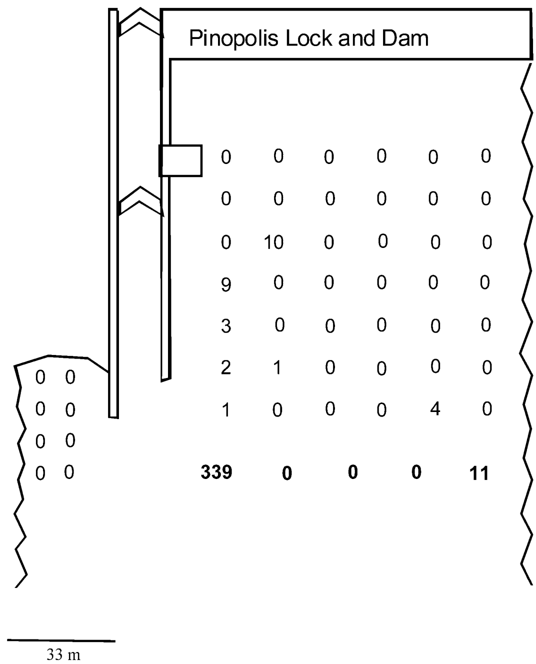

FIGURE 1.—Grid locations (indicated by numbers 0–339) of egg mats (normal type) and plankton nets (bold type) in relation to Pinopolis Lock and Dam during sampling (February 10 to April 30, 2002) for shortnose sturgeon eggs. Numbers indicate total number of eggs at that location.

to the structure to provide added stability during deployment in high current. Numbered buoys were attached to each mat for identification. Four 1-kg lead dive weights were attached as anchors. Up to five (two from March 5 to March 25, five from March 25 to March 27, four from March 27 to April 10, three from April 10 to May 1) D-shaped plankton nets (1 m diameter × 3 m long; 1-mm or 2-mm mesh) were tethered on anchors to the river bottom, and were marked with numbered buoys. Nets were positioned at the downstream end of the egg mats to capture any nonsettling, dislodged, or dead eggs, and newly hatched larvae (Kieffer and Kynard 1996; Figure 1).

Egg mats were examined, and surface and bottom water temperature and dissolved oxygen were measured daily from February 12 to May 1, 2002. Plankton nets were examined daily from March 5 to May 1, 2002. All eggs were removed with soft-tipped forceps and placed into 20-mL plastic vials containing 10% solutions of buffered formalin. Eggs were returned to the laboratory for taxonomic identification and developmental stage determination. Eggs were sorted by developmental stage and classified as either early (stages 1–9), mid (stages 11–19), or late (stages 20–35) development for the purpose of age estimation (Ginsburg and Dettlaff 1991). Because both stage duration and variability in the timing of developmental stage increase as development proceeds, age was determined to the nearest hour for eggs in the early stage of development and the nearest day for eggs in the mid and late stages of development. Spawning time for eggs in the early stage of development was estimated from the developmental-stage-at-age relationship for shortnose sturgeon eggs incubated at 16°C (B. Wayman, U.S. Fish and Wildlife Service, Warm Springs, Georgia, unpublished data), adjusted according to the relationship between temperature and mitotic cleavage cycle duration developed for Russian sturgeon *A. gueldenstaedti* (Ginsburg and Dettlaff 1991; Duncan 2003) and white sturgeon *A. transmontanus* (Beer 1980; Wang et al. 1985). Spawning dates for eggs in the mid and late stages of development were estimated from the developmental-stage-at-age relationship for Russian sturgeon eggs incubated at 18°C (Ginsburg and Dettlaff 1991), adjusted according to the relationship between temperature and mitotic cleavage cycle duration developed for Russian sturgeon (Ginsburg and Dettlaff 1991; Duncan 2003). Based on the variability in stage duration, we estimate the precision of this technique to be ±3 h for the early stage, ±12 h for the mid stage, and ±24 h for the late stage. Consequently, spawning time estimates of within 6 h were conservatively assumed to represent samples from the same spawning event.

The effects of flow on spawning date were evaluated using a *t*-test. The relationships of flow and time of day on spawning times for eggs collected in the early stage of development were evaluated with a chi-square test. For purposes of analysis, days were divided into dawn (0600–0800 hours), day (0800–1800 hours), dusk (1800–2000 hours), and night (2000–0600 hours).

Results

Eggs were collected on 17 of 21 d sampled from March 4 to 25, 2002, at water temperatures of 10–16°C (Figure 2). We collected 28% of the eggs on March 8 when the water temperature was 11°C. A total of 30 shortnose sturgeon eggs were collected from egg mats, and 338 eggs and 1 newly hatched yolk sac larva were collected from plankton nets (Figure 1). Eggs were collected on only 7 of the 50 egg mats, and 87% of these eggs were collected from mats near the navigation lock wing wall. The

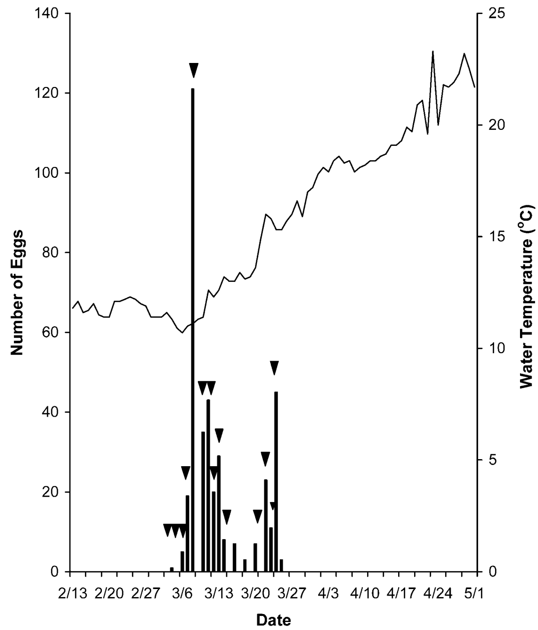

FIGURE 2.—Number of shortnose sturgeon eggs (solid bars) collected in plankton nets and on egg mats from the Pinopolis Dam tailrace in relation to bottom water temperature (line) and sample date in 2002. Triangles indicate spawning dates backcalculated from egg developmental stages.

other eggs (13%) were collected from one mat on the opposite side of the tailrace canal at the downstream end of the array. More than 95% of eggs collected from plankton nets were collected from the net at the terminus of the egg mats near the navigation lock wing wall. On 10 occasions, plankton nets collected eggs when no eggs were collected from egg mats. On two occasions, two egg mats collected eggs when eggs were not collected in the related downstream plankton nets.

Approximately 16% of eggs collected from egg mats and 44.5% of eggs collected from plankton nets were damaged or deformed and were not processed further. Undamaged specimens ranged in age from newly spawned, undivided eggs to fully developed, hatching larvae. Over 66% of eggs from egg mats were in the early stage of development, but only 5% of eggs from nets were in the early stage. Of the eggs in the mid stage of development, 3% were collected from mats and 97% from plankton nets. All eggs from the late stage of development were collected in plankton nets. Although eggs were collected on 16 dates, eggs less than 24 h old were only collected on just 6 dates. Eggs between 24 and 48 h old were col-

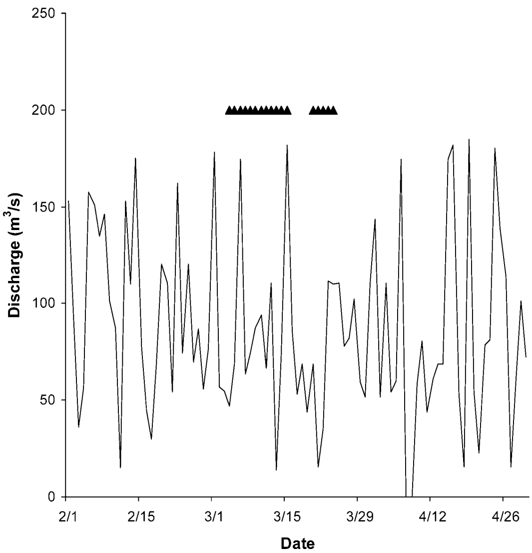

FIGURE 3.—Mean daily discharge in the Pinopolis Dam tailrace over the study period. Triangles indicate shortnose sturgeon spawning dates based on collections of eggs in the early, mid, and late developmental stages.

lected on five occasions that backcalculated to dates when no early stage eggs were collected, suggesting five additional spawning dates. Further, on 11 occasions plankton nets collected eggs that were spawned on dates not indicated by egg mat sampling. Spawning times for eggs in the early stage ranged from 0034 to 2112 hours for eggs from mats and from 0005 to 1330 hours for eggs from plankton nets. Based on spawning time estimates, we estimated that a minimum of nine independent spawning events took place on these six dates. Combined with a minimum of 11 additional spawning events, based on eggs in later stages of development, a minimum of 20 spawning events occurred in the tailrace during the 2002 spawning season.

Peak mean daily discharge remained relatively low (Figure 3), and no relationship between mean daily discharge and spawning date was detected ($t = -0.07$, df = 29, $P = 0.9451$). No relationship between presence or absence of discharge and spawning times for eggs collected in the early stage was detected ($\chi^2 = 0.0334$; df = 1, 1; $P = 0.8551$; Figure 4). Within each day, hydro peaking resulted in discharges occurring during dawn, dusk, and night hours (Figure 4). Although shortnose sturgeon spawned more often during night than at any other time of day, independent of generation, no relationship was detected ($\chi^2 = 5.1415$; df = 1, 3; $P = 0.1617$).

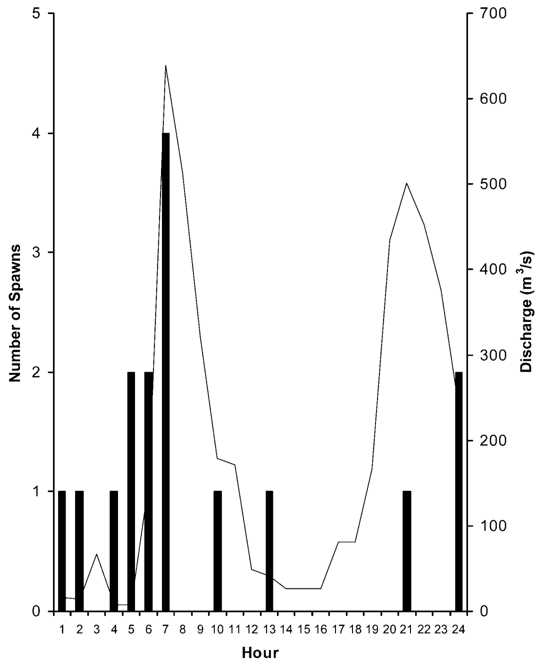

FIGURE 4.—Mean hourly discharge (line) at Pinopolis Dam on dates when shortnose sturgeon spawning occurred and the number of spawns per hour of the day (0100 to 2400 hours; solid bars) as determined from eggs collected in the tailrace.

Discussion

Water temperatures recorded in Pinopolis Dam tailrace during the 2002 spawning period were similar to water temperatures reported in other river systems during periods of sturgeon spawning (Dadswell 1979; Taubert 1980; Buckley and Kynard 1985; Hall et al. 1991) and were consistent with those in previous records of shortnose sturgeon spawning in this system (Cooke and Leach 1999). In southern river systems, these temperatures are achieved earlier (mid-February or early March) than in northern river systems (late April or early May; Buckley and Kynard 1985; Hall et al. 1991; Kieffer and Kynard 1996). Unseasonably warm weather in January resulted in temperatures in the tailrace exceeding the minimum spawning temperatures of shortnose sturgeon before the initiation of sampling. Although it is possible that some sturgeon spawned during this period, no record of January spawning has been previously reported. Water temperatures in excess of the minimum preferred spawning temperature for shortnose sturgeon were recorded in February at the initiation of the study, yet spawning was first detected on March 4, 2002.

Although eggs were collected from both egg mats and plankton nets, the latter collected 92% of all eggs. Plankton nets were not deployed until March 5, several days after egg mats documented spawning. Further, no more than two plankton nets were deployed during the period when spawning was detected. It is possible that earlier and additional deployment of plankton nets could have detected earlier or additional shortnose sturgeon spawning. As suggested by other studies, we found egg mats were more effective in determining fine-scale location (Fox et al. 2000; Paragamian et al. 2001; Paragamian and Wakkinen 2002; Paragamian et al. 2002). We also found plankton nets had a higher catch rate and provided presence information on a broader time scale and with less effort, as suggested by previous work (Auer and Baker 2002; Perrin et al. 2003). The location of egg collections suggest the lock wing wall may be positively selected by spawning shortnose sturgeon. The area on the opposite side of the lock wing wall may also be selected by spawning sturgeon. Several studies have found that sturgeon prefer to spawn where the greatest water velocity occurs (Kempinger 1988; Bruch and Binkowski 2002). Because substrate in these areas is similar to that in other areas, variability in secondary microhabitat characteristics, such as current velocity in these locations may effect spawning site selection.

The substrate in Pinopolis Dam tailrace does not consist of material typically preferred by shortnose sturgeon (Taubert 1980; Buckley and Kynard 1985; Kieffer and Kynard 1996). Hall et al. (1991) found that shortnose sturgeon in the Savannah River utilized spawning grounds near sharp river bends near hard-packed clay areas where no sediment was allowed to accumulate. In other river systems, shortnose sturgeon utilized the deepest part of the river channel to ensure egg survival (Hall et al. 1991; Kieffer and Kynard 1996). Although the substrate in the tailrace is not optimal, it may be suitable for shortnose sturgeon spawning based on depth and sediment criteria, and sturgeon may opt to spawn here because migration to historic spawning areas is blocked.

Only a few species of North American sturgeon have been examined to determine the relationship between temperature and embryonic cleavage rate (Beer 1980; Wang et al. 1985; Ginsburg and Dettlaff 1991). Because no relationship between developmental stage, temperature, and age exists for shortnose sturgeon, we estimated this relationship by comparing shortnose sturgeon developmental rates (B. Wayman, US Fish and Wildlife Service, Warm Springs, Georgia, unpublished data) with rates published for other species. Several studies examining white sturgeon spawning experienced errors of as much as 4 h when backcalculating spawning dates (Paragamian and Wakkinen 2002; Perrin et al. 2003). Developmental rates were chosen to be conservative, so if errors occurred, we probably underestimated the number of spawning events.

Egg mats captured eggs that were much earlier in development, and the eggs probably attached to the mats during spawning events. In previous studies, newly spawned eggs (<48 h old) collected on egg mats were indicators of spawning by white and Gulf sturgeon *A. oxyrinchus desotoi*(Fox et al. 2000; Paragamian et al. 2001; Paragamian and Wakkinen 2002; Paragamian et al. 2002), based on dermersal and adhesive characteristics of sturgeon eggs (Dadswell 1984; Wang et al. 1985; Kempinger 1988; Kynard 1997; Perrin et al. 2003). Over 50% of eggs collected from egg mats could be aged to within 3 h of spawning time.

Conversely, the use of plankton nets to precisely link collection time with spawning time was only possible for 33% of the eggs collected and only on 2 of 16 dates. Eggs collected in nets were generally more than 24 h old and were probably dislodged some time after spawning. Kempinger (1988) observed, over a 16-h period, that increase in dam discharge dislodged eggs of lake sturgeon *A. fulvescens* from galvanized trays used as spawning substrate. Because the generation source and generation intensity varied, it is possible that some eggs were dislodged by a change in current direction as well as current magnitude.

No relationship between spawning date and mean daily discharge on or before that date was detected. However, the affects of flow on spawning could not be adequately tested because of the narrow range in discharge resulting from mandated minimum and maximum discharge requirements for the dam. Buckley and Kynard (1985) found that flow was more important than substrate in determining spawning location. Most spawning events occurred during night periods, when power generation normally occurred, and a few spawning events occurred during dawn generation periods. However, several spawning events occurred during the day during periods of nonpower generation. Consequently, no relationship between spawning and generation was detected. Spawning occurred more often during night hours than any other period of day regardless of generation, but differences were not significance because of the sample size of eggs in the early stage of development was too limited. Bruch and Binkowski (2002) occasionally observed a small number of lake sturgeon spawning at night but did not find significance in spawning and time of day. Because generation normally occurred at night, the preference for shortnose sturgeon to spawn during nongeneration periods could not be fully evaluated.

Consistent with the conclusions of others, we found that shortnose sturgeon spawn over a relatively short period when environmental conditions are suitable for maturation and development of eggs (Taubert 1980; Buckley and Kynard 1985; Ginsburg and Dettlaff 1991). Although only one larval shortnose sturgeon was collected, no larvae or juveniles have previously been collected from the system. This indicates that shortnose sturgeon eggs can successfully develop and hatch in Pinopolis Dam tailrace, but recruitment success is still unknown. Additional research to collect and assess the juvenile populations would aid in management efforts of the Cooper River shortnose sturgeon population.

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